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Sidon on the breadth of the wild sea: Movement and diet on the Mediterranean coast in the Middle Bronze Age

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Abstract

Objectives: Excavations at Sidon (Lebanon) have revealed dual identities during the Middle Bronze Age (ca. 2000–1600 BCE): a maritime port and center for local distribution, as well as a settlement with a heavy subsistence dependence on the extensive inland hinterlands. We aim to investigate residential mobility at Sidon using isotopic analyses of 112 individuals from 83 burials (20 females, 26 males, and 37 subadults). Veneration and remembrance of the dead is evident from funerary offerings in and near the tombs. With marine fish a major component in funerary offerings, we predict major marine reliance in this coastal population.

Materials and methods: New isotopic evidence of paleomobility ($^{87}Sr/^{86}Sr$, $\delta^{18}O$) and diet ($\delta^{13}C_{carbonate}$) is the focus of this research. Previous bulk bone collagen $\delta^{13}C$ and $\delta^{15}N$ analysis is strengthened by further sampling, along with $\delta^{34}S$ where collagen yield was sufficient.

Results: The five non-locals identified (8.9% of the 56 analyzed) come from constructed tombs with high-status grave goods except for one, which was heavily disturbed in antiquity. Dietary investigation of the population confirms reliance on terrestrial resources with no significant marine input. No significant differences in diet between the sexes or burial types are present.

Conclusions: Although Sidon was part of a growing Mediterranean network evidenced through artefactual finds, relatively low immigration is evident. While religious feasts venerating the dead may have involved significant piscine components, no appreciable marine input in diet is observed. Fish may have been reserved for the deceased or only consumed on feast days alongside the dead rather than a regular part of the Bronze Age menu.

KEYWORDS
carbon, Levant, stable isotopes, strontium, nitrogen, oxygen

1 | INTRODUCTION

Steady political conditions during the Middle Bronze Age (MBA, ca. 2000–1600 BCE) allowed coastal cities to contribute to far-reaching trade networks that connected Eurasia over large distances. Pottery and cylinder seal impressions from the Early Bronze Age (EBA, ca. 3200–2000 BCE) and MBA suggest that the city of Sidon, in modern Lebanon, was one of the nodes along this network:

conducting long-distance trade of goods and ideas with Egypt, Cyprus, and Crete and inland regions to the south and east (Bader et al., 2009; Doumet-Serhal, 2008). There is also archaeological evidence of Sidonians exporting olive oil, wine, and cedar while importing luxury items such as Anatolian silver, Cypriot copper ore, and Egyptian artifacts as well as more quotidian objects like fish and wheat (Charaf, 2014; Doumet-Serhal, 2004; Veron et al., 2011).

We aim to investigate reliance on and interaction with communities outside of Sidon using isotopic analyses of 112 individuals from 83 burials (20 females, 26 males, and 37 subadults). Using archaeological chemistry, specifically isotopic analysis, we have opportunities to identify general trends of diet and mobility within an assemblage representing the MBA population of Sidon, as well as investigate patterns at the individual level. New isotopic evidence of paleomobility (^{87}Sr/^{86}Sr, δ^{18}O) and diet ($\delta^{13}C_{carbonate}$) is the focus of this research. Previous bulk bone collagen δ^{13}C and δ^{15}N analysis (Schutkowski & Ogden, 2011) is strengthened by further sampling of the assemblage, along with δ^{34}S where collagen yield was sufficient.

The interconnectedness of Sidon based on archaeological evidence of its subsistence and economy would imply the city was a cosmopolitan center with many non-local inhabitants. If there are many non-locals buried in this cemetery, it may explain the lack of marine dietary resources evidenced in previous research (Schutkowski & Ogden, 2011). Isotopic investigations of mobility will clarify whether the unexpected dietary signature can be explained by many people in the assemblage having a homeland further inland.

Further, the presence of non-local individuals in this cemetery could explain the mortuary variability seen at the site, with individuals identified as “local” having a unified mortuary practice distinct from those originating elsewhere. With the stone-lined constructed tombs assumed to suggest a more elite individual or group of people, we predict that those interred within those constructed tombs, compared with those buried in other grave types, will be more often local, having grown up in Sidon and established a base of power in this urban center. We also predict that those buried in constructed tombs will have been afforded more high-status foods in life that may be evident through dietary isotopic analysis. Many high-status foods, such as imported olive oil and wine, might be difficult to identify isotopically, but greater consumption of highly valued animal flesh and dairy products would cause higher relative δ^{15}N values.

1.1 | The Sidon College Site

The Sidon College Site, so named after the American and Marist Colleges that stood at the site previously, was chosen as an excavation site in 1998 by the British Museum and the Directorate General of Antiquities (DGA) of Lebanon. The DGA purchased the downtown College Site along with two other large pieces of prime real estate for the purposes of archaeological preservation (Doumet-Serhal et al., 2004).

Over 20 years later, the excavation is still ongoing, with the site providing continuous stratigraphic evidence from the Late Chalcolithic to Roman and Medieval Crusader periods (Doumet-Serhal, 2003a; Doumet-Serhal et al., 2004). The site shows evidence of substantial public and religious architecture dating to the Early, Middle, and Late Bronze Age as well as the Iron Age when Sidon became established as a major port city alongside Tyre and Byblos (Carayon, 2019; Pfälzner, 2012). Indeed, ancient texts later used the term “Sidonians” as shorthand for Phoenicians in general, such was the city's cultural and politicoeconomic prominence (Sommer, 2007).

Following the Early Bronze Age occupation, major change in site function occurred during the Middle Bronze Age, when the site was deliberately covered with 90 to 140 cm of cleaned beach sand and the area transformed into a burial ground, with activity occurring around the burials from the transition MB IIA/IIB and the construction of a temple in MBIIB (Doumet-Serhal, 2010; Ownby & Griffiths, 2009).

Burials from the MBA display sophisticated and socially diverse funerary rituals. The earliest graves, ca. 2000–1750 BCE, are mudbrick and/or stone tombs constructed for individuals buried with jewelry and bronze weaponry. It is at this phase when we see the so-called “warrior burials,” single inhumations with metal weapons, often bronze duckbill axe heads at Sidon, that are interpreted as having ascribed value suggestive of individual social status (Doumet-Serhal, 2008). This warrior burial typology is observed across the Levant during this time period (Cohen, 2012; Philip, 1995; Prell, 2019).

Single burials with some multiple inhumations are found in the MBIIB (ca. 1750–1650 BCE). While luxury funerary goods such as silver jewelry and bronze weaponry became rarer, funerary rites, involving meals or feasting continued during the MBIIB with the inclusion of butchered faunal remains (Chahoud & Vila, 2012). Curved knifes used for the butchering process are placed within some graves. Bread ovens, mortars and grinding stones are found close to the burials, containing the remains of wheat, barley, legumes, chickpeas, lentils as well as fruit and nuts. Postholes for tents are found around these areas. Jar burials are also found during this period; while some jars are infant burials which are not uncommon in this region (Blackham et al., 1997; Ilan, 1995), there are also some jar burials containing secondary deposits of older children and one adult. This practice, though less common than infant jar burials, has been observed in some contemporaneous Near East sites (Hornig & Jungklaus, 2010; Witzel et al., 2000). Multiple inhumations, potentially family tombs, become the most common practice about 1650 BCE; at this time, commemorating practices no longer take place by the tombs but have instead been moved to the temple (Doumet-Serhal, 2017).

1.2 | The Levantine menu and previous isotopic research at Sidon

The typical Bronze Age menu for this region is a reliance on C_3 crops with domesticates (e.g., ovicaprines, cattle, and pigs) (Zohary & Hopf, 2000). C_3 cultivated crops included cereals such as emmer (*Triticum dicoccon*) and barley (*Hordeum vulgare*) along with *Allium* spp. (e.g., onions and leeks), melon (*Cucumis melo*), sesame (*Sesamum spp.*)

and pulses such as lentils and peas (*Pisum* spp.). Many of these plants have been observed in the archaeobotanical evidence from the site (De Moulins & Marsh, 2011; Kislev & Bar-Yosef, 1988; Sebastian et al., 2010). Millet (*Panicum miliaceum*) was present in the Near East since the Neolithic as a wild plant for grazing and gathering (Hunt et al., 2008) but was only introduced as a supplementary summer crop to the ancient Near East by the Iron Age (Riehl & Nesbitt, 2003). Archaeobotanical evidence suggests that date palm (*Phoenix dactylifera*) was present from the EBA in northern coastal Lebanon (Damick, 2019) and might have already been cultivated for fruit and palm wine in Sidon by the MBA. Archaeobotanical investigations on the Sidon coast found some evidence of *Phoenix* plants, as well as olive (*Olea europaea* L.) (Orendi & Deckers, 2018), corroborating with the artifactual evidence of olive cultivation for consumption and trade. Other tree crops likely cultivated in the Bronze Age Near East include the apple (*Malus* spp.), citron (*Citron medico*), fig (*Ficus carica*), and pistachio (*Pistacia vera*), and some of these fruits and nuts could be gathered from the wild as well (Hormaza et al., 1994; Kislev et al., 2006; Spengler, 2019; Zohary & Hopf, 2000). Although likely not consumed in large quantities, it is also worth noting that long-distance trade could have brought in plants not cultivated locally such as dried spices and possibly even soy (Scott et al., 2021).

The hinterlands to the east of Sidon's urban center are estimated to have been relied upon for agricultural pursuits (Orendi & Deckers, 2018). Littoral and open water fishing are evident from the taxa identified at Sidon although mostly coastal and pelagic fish are present, interpreted as heavy inshore activity (Chahoud & Vila, 2012). Some freshwater species are present including Nile perch (*Lates niloticus*) which would have been an import from Egypt (van Neer, 2006). Hunting was a large component of meat procurement at Sidon during the EBA but became only a minor contribution by the MBA (Chahoud & Vila, 2012).

Feasting was not just for the living in this region. During the MBA, feasts known as *kipsum* in Mesopotamia were practiced throughout the Near East to honor and appease dead ancestors, especially the elite and ruling classes. Food and drink were prepared, offered to the dead near or inside tombs, and sometimes partially consumed by the living as a form of meal-sharing in a ritualized setting (Bayliss, 1973; Kharobi & Buccellati, 2017; Zwitser, 2017). At Sidon, animals interpreted to be offerings have been found in some constructed tombs. These animal offerings were mostly ovicaprines, either whole young animals or meat-rich limbs, although whole fish from the Mediterranean were also offered to the dead in Sidon (Chahoud & Vila, 2012; Doumet-Serhal, 2003a).

Previous stable isotope analysis of diet at Sidon sought to characterize the general dietary profile of the population with human bulk bone collagen of some of the adults excavated, along with a dietary baseline of Bronze Age animal bones from the site (Schutkowski & Ogden, 2011). Schutkowski and Ogden found generally good collagen preservation in the human ($n = 38$), domesticated mammal ($n = 34$), and fish bones ($n = 12$) analyzed for δ^{15}N and δ^{13}C. Schutkowski and Ogden aimed to generally characterize Sidonian diet, presenting their human isotopic data against their dietary baseline as well as comparing the sexes. The human values trended with the terrestrial animals and seemingly little or no marine input, and there were no observable differences between males and females. Now, we have opportunity to expand Schutkowski and Ogden's research with more individuals as well as other isotopic data beyond δ^{13}C and δ^{15}N from bulk bone collagen.

Schutkowski and Ogden's findings that there was no appreciable marine component to any Sidonian's isotopic composition was in opposition with the fish offerings given as meals for the dead found at the site. One possibility is that the recovered burials are mostly of non-locals buried in the Sidon cemetery who spent enough of their lives inland to generate a generally non-marine isotopic signature or came from a place where the food culture did not include marine foods. Isotopic analysis of paleomobility might elucidate why these coastal peoples were not making use of the rich marine environment.

2 | PRINCIPLES OF ISOTOPE ANALYSIS

2.1 | Isotopic analysis of paleomobility

While artifacts provide indirect evidence of human movement and contact in the past, recent scientific analyses in the wider region have revolutionized our insights beyond the movement of goods and allow direct investigation of the movement of individuals (Agranat-Tamir et al., 2020; Ingman et al., 2021; Skourtanioti et al., 2020). Isotopic values from biological tissues are useful for understanding movement within an individual's lifetime, as these values can be reflective of the environment an individual lived in when these tissues were formed (Budd et al., 2004). To date, no paleomobility studies have been published on human remains from Lebanon. However, strontium and oxygen isotopic data have been utilized in Bronze Age settlements Sidon might have had cultural contact and trade relations with, in the modern countries of Egypt (Stantis, Kharobi, et al., 2020), Jordan (Gregoricka et al., 2020), Syria (Sołtysiak, 2019; Sołtysiak, 2020), and southern Turkey (Ingman et al., 2021).

The interpretation of movement using strontium isotope analysis rests upon the assumption that the ^{87}Sr/^{86}Sr ratios of an individual's body tissues will generally reflect the ^{87}Sr/^{86}Sr ratios of the underlying geology in which they lived when these tissues were forming (Bentley, 2006; Montgomery et al., 2005). Due to its similar atomic radius, strontium readily replaces calcium in minerals, including calcium in bones and teeth (Burton, 2008; Lewis & Evans, 2003). Erosion of the underlying geological formations is the major contributor to ^{87}Sr/^{86}Sr biospheric values (Evans et al., 2009; Evans et al., 2010), although recent research suggests that modern agricultural fertilizing practices may change ^{87}Sr/^{86}Sr ratios of the soil, affecting the rest of the biosphere (Thomsen & Andreasen, 2019). There is no appreciable fractionation across trophic levels or in metabolic processes (Lewis et al., 2017), allowing direct comparison from the bioavailable strontium ratios to humans buried in the area.

Oxygen stable isotope analysis (δ^{18}O) is common method of investigating individual movement, paired with ^{87}Sr/^{86}Sr or analyzed

on its own (Chenery et al., 2010; Müldner et al., 2011; Prowse et al., 2007). The main intake of oxygen atoms into the body is through ingested water (Bryant & Froelich, 1995; Longinelli, 1984; Luz & Kolodny, 1989), and the difference in proportions between ^{18}O and ^{16}O is dependent largely on the location's climate (e.g., mean temperature, altitude, proximity to coast) from which the drinking water is sourced as opposed to the information ^{87}Sr/^{86}Sr provides of the underlying geology (Daux et al., 2008; Pederzani & Britton, 2018). Oxygen can be analyzed from two functional groups within hydroxyapatite: the phosphate (-PO_4) or the carbonate (-CO_3) group. The phosphate group is more tightly bound and less susceptible to diagenetic alterations (Chenery et al., 2012), but the stable isotope analysis of the structural carbonate ion also provides $\delta^{13}C_{carbonate}$ data for dietary information (Commendador et al., 2019; Gregoricka et al., 2020; King et al., 2013).

2.2 | ^{87}Sr/^{86}Sr and δ^{18}O variation in Lebanon

The geology of Lebanon is largely sedimentary deposits with a few basaltic flows and intrusions to the northern and southern edges, with narrow bands of metamorphics around the edges of these intrusions (Figure 1). Sidon is a coastal city, on Quaternary dunes and lake sedimentary deposits (Walley, 1998). However, much of the arable land could have been east, on the nearby chalk and limestones. Directly east and southeast, the hinterlands are dominated by chalks and limestones from the Upper Cretaceous (Senonian) and Neogene periods. To the north are fluvio-deltaic sandstones overlain by thick marine limestones from the Lower and Middle Cretaceous periods.

There have been no comprehensive ^{87}Sr/^{86}Sr analyses of Lebanese geology to date, although there have been some targeted

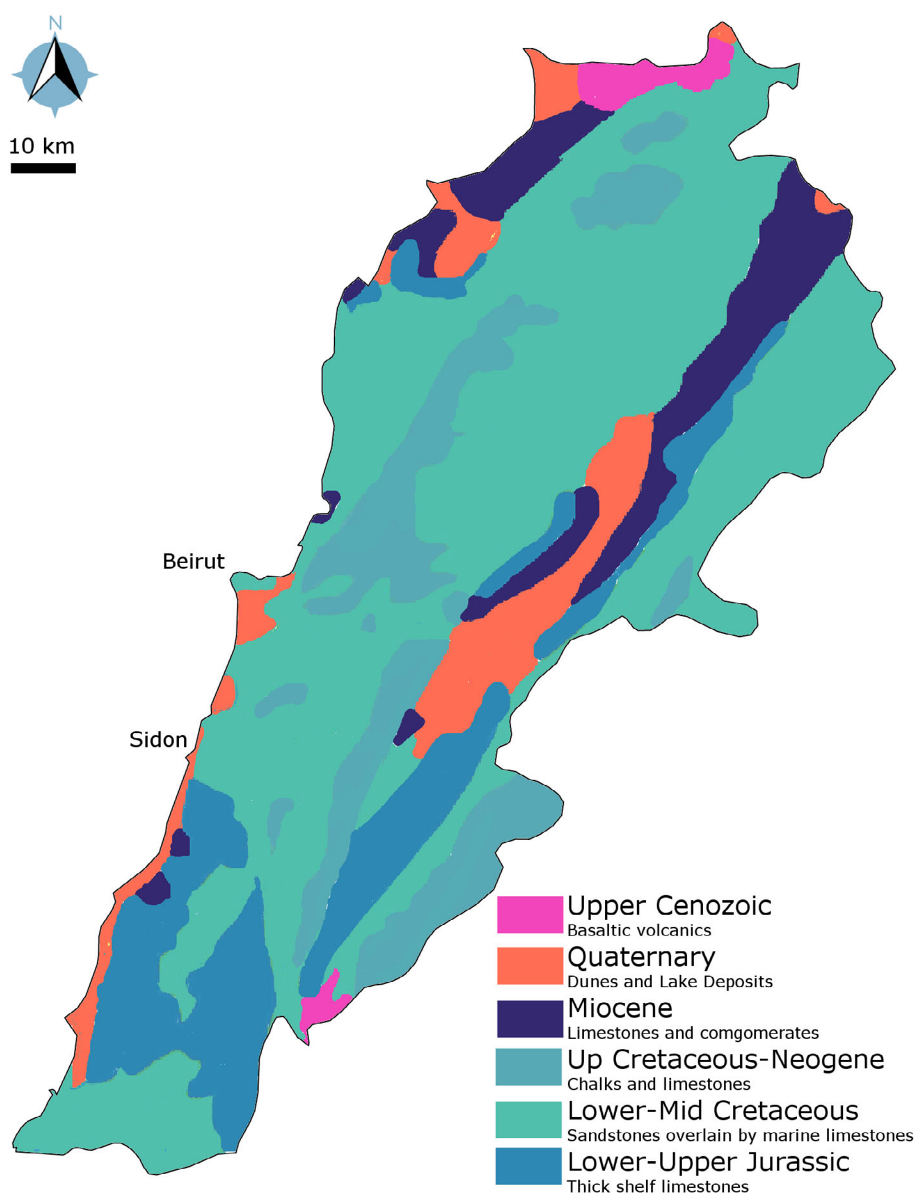


FIGURE 1 Geological map of Lebanon with Sidon and the capital of Beirut highlighted. Modified from Walley, 1998

analyses of specific formations. Jurassic sedimentaries in the north-central region range from 0.707095 to 0.707844 (Nader et al., 2004) and the Cenozoic basalts in northern Lebanon range from 0.703317 to 0.703579 (Abdel-Rahman & Nassar, 2004). Geological baseline $^{87}Sr/^{86}Sr$ values are less reliable for establishing bioavailable $^{87}Sr/^{86}Sr$ ranges due to geologic mixing in an area along with exogenous sources such as loess or seaspray (Bentley, 2006; Whipkey et al., 2000). Instead, biospheric ranges from flora and fauna are expected to be better reflections of the averaged environmental ranges within a given area.

There are no comprehensive biospheric ranges in Lebanon to date, either. Rich et al. (2016) collected preliminary $^{87}Sr/^{86}Sr$ ratios from five forest sites along the Mount Lebanon range and Henderson et al. (2009) included one plant sample from Beirut in their sampling strategy that mostly targeted Syria. There are biospheric data from Northern Israel captured on some of the same geological formations as found in southern Lebanon (Hartman & Richards, 2014); these can be compared and discussed in the absence of Lebanese data.

In order to consider possible proxy values for the oxygen stable isotope values ($\delta^{18}O_{dw}$), modern mean annual precipitation oxygen values across the region have been recorded (Bowen, 2018; Bowen et al., 2013). When plotted (Figure 2), variation is observable, especially to the south where it is hotter and more arid, and in cooler regions such as mountain ranges. Calculated annual mean oxygen values for modern Sidon are -5.2 ± 0.3 (Bowen, 2018). Drinking water from the nearby river of Nahr al-Awali would have also been available.

2.3 | Isotopic analysis of diet

Investigation of the isotopic composition of archeologically derived teeth and bones can provide valuable information about diet and environmental conditions in the past (Lee-Thorp, 2008). The analysis of carbon stable isotope analysis ($\delta^{13}C$) is based on the principle that most of the differences in carbon stable isotope values within food webs arise from the varying $\delta^{13}C$ values of autotrophs due to different photosynthetic pathways (DeNiro & Epstein, 1978; Hoefs, 2009; Lee-Thorp et al., 1989; Sharp, 2017; Tieszen, 1991). Terrestrial C_3 plants use the Calvin cycle to fixate carbon from atmospheric CO_2 and will display a $\delta^{13}C$ range between -33 and -23‰ (Marshall et al., 2007; Sharp, 2017). Aquatic photosynthetic organisms generally follow a C_3 photosynthetic pathway, but many types of marine algae and cyanobacteria utilize sources of carbon with higher $\delta^{13}C$ values, such as oceanic bicarbonate, which results in the correspondingly higher $\delta^{13}C$ values compared with terrestrial C_3 plants, often between -22 and -17‰ (Fry et al., 1982; Keegan & DeNiro, 1988; Schoeninger et al., 1983). Freshwater autotrophs derive their carbon from a variety of sources including atmospheric CO_2, dissolved CO_2, soil bicarbonate, and carbon from organic detritus (Zohary et al., 1994). As a result freshwater fish bones have yielded more variable $\delta^{13}C$ values than marine fish, ranging between -13 and -25‰ (Katzenberg & Weber, 1999). Plants that use the C_4 (Hatch-Slack) photosynthetic pathway, such as maize, millet, and sorghum display higher $\delta^{13}C$ values compared with terrestrial C_3 plants, typically between -16 and -9‰, largely overlapping in values with marine autotrophs (Sharp, 2017).

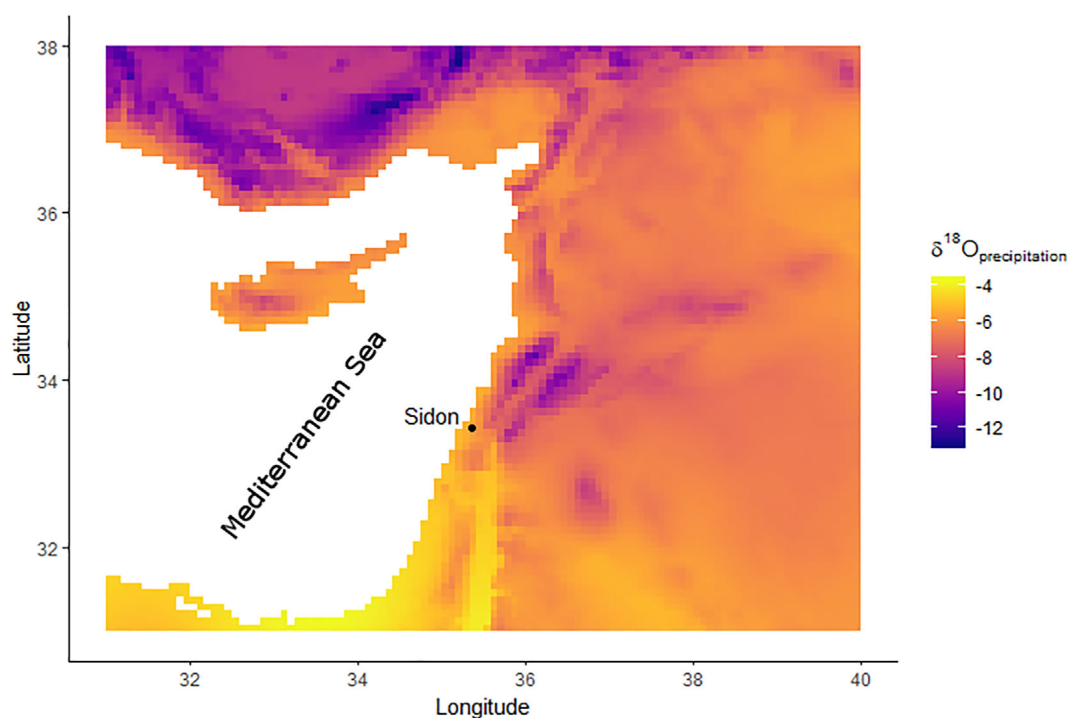


FIGURE 2 Modern mean annual precipitation values of $\delta^{18}O$ across the region. Data from Bowen, 2018

Stable isotope ratios in consumer tissues are related to dietary values with high fidelity, but differences in fractionation factors between tissues must be recognized in order to investigate dietary patterns (Hobson & Clark, 1992; Tieszen et al., 1983). The carbon stable isotope composition of structural carbonate (-CO_3) from bone or tooth hydroxyapatite reflects the isotopic composition of the whole diet (carbohydrates, lipids, and protein) (Balasse et al., 2003; Passey et al., 2005). In contrast, $\delta^{13}C_{collagen}$ largely tracks the protein portion of an individual's diet due to the differences in the metabolic processes involved in creating hydroxyapatite and collagen (Ambrose & Norr, 1993; Jim et al., 2004; Lee-Thorp et al., 1989; Tieszen & Fagre, 1993). The carbonate-collagen offset ($\Delta^{13}C_{carbonate\text{-}collagen}$) can be examined to compare the whole diet to the protein portion: controlled diet studies show evidence that if the offset is greater than 4.5‰ the protein portion is dominated by C_3 terrestrial foods with relatively more C_4/marine whole diet sources while an offset less than 4.5‰ suggests a diet of marine protein sources with terrestrial C_3 whole diet (Ambrose & Norr, 1993; Jim et al., 2004).

The nitrogen stable isotope values ($\delta^{15}N$) in collagen are largely reflective of the protein portion of diet as well but are indicative of the individual's place in the food web or trophic level. There is a roughly 3–5‰ stepwise enrichment between predators and prey, with more complex marine food webs resulting in higher $\delta^{15}N$ values in higher-level marine carnivores compared with terrestrial carnivores (Bocherens & Drucker, 2003; Minagawa & Wada, 1984; Perkins et al., 2014). Because of this phenomenon, $\delta^{15}N$ values of collagen can be used in conjunction with $\delta^{13}C$ values to assess an organism's reliance on marine versus terrestrial resources. There is also a stepwise enrichment of ^{13}C between trophic levels but the enrichment is often too small (~1‰) to be easily observed except in controlled dietary studies (Bocherens & Drucker, 2003; DeNiro & Epstein, 1978). Multivariate statistics can be used to visualize different protein and energy sources with three of the isotopic data collected here ($\delta^{13}C_{carbonate}$, $\delta^{13}C_{collagen}$, and $\delta^{15}N$) (Froehle et al., 2010; Froehle et al., 2012; Kellner & Schoeninger, 2007).

Studies are proving that sulfur stable isotope analysis ($\delta^{34}S$) is another useful tool to help differentiate between the consumption of marine, terrestrial, and freshwater foods in past populations (Buchardt et al., 2007; Cheung et al., 2017; Craig et al., 2006; Privat et al., 2007; Richards et al., 2001; Richards et al., 2003; Stantis et al., 2015). Sulfur is present in animals in the amino acid methionine, which contributes about 0.46% of collagen by weight in animal bone (there is another sulfur-containing amino acid, cysteine, but it is only present in trace amounts in bone collagen) (Brosnan & Brosnan, 2006; Nehlich, 2015). Unlike carbon and nitrogen, there is little isotopic discrimination during sulfur uptake in autotrophs; primary producers will have essentially the same $\delta^{34}S$ values as their sulfur source (Kennedy & Krouse, 1990; McCutchan et al., 2003; Trust & Fry, 1992).

Marine autotrophs display $\delta^{34}S$ values similar to the oceanic sulfate reservoir (+20.99‰), between +17 and +21‰ (Peterson & Fry, 1987; Rees et al., 1978). Terrestrial plants draw upon sulfur in the soil, underlying bedrock and atmosphere and will display greater $\delta^{34}S$ variation than marine plants, typically within a range of −5 to +10‰ (Nriagu et al., 1991; Peterson & Fry, 1987). Freshwater plants vary greatly and produce values roughly analogous to terrestrial primary producers, making a comparison between freshwater and other food sources difficult (Peterson & Fry, 1987; Privat et al., 2007). Sea-spray (salt-water aerosols from crashing waves or high winds) and marine-derived precipitation may alter $\delta^{34}S$ values in coastal regions, creating homogeneous "marine" values in human tissue even when terrestrial foods are the main form of subsistence (Richards et al., 2001). By examining $\delta^{13}C$ and $\delta^{15}N$ values simultaneously with $\delta^{34}S$ values, differentiating between sea-spray effect and marine diet is feasible.

Building a dietary baseline aids bioarchaeologists in placing ancient humans in their environment. There are slight but significant variations around the globe for carbon, nitrogen, and sulfur isotope values of plant and animal life due to variable rainfall, soil conditions, climate, and other factors (Casey & Post, 2011). These differences in stable isotopes values have even been used to consider childhood place of origin in past populations (Cheung et al., 2017; Schroeder et al., 2009; Stantis et al., 2016), and the highly varied sulfur values in environments have been utilized in ecological and archeological studies to track human and animal migrations and diet (Hesslein et al., 1991; Peterson et al., 1985; Richards et al., 2001; Thomas & Cahoon, 1993).

The archeologically derived bone of domesticates and marine fish analyzed by Schutkowski and Ogden (2011) will be used as a dietary baseline for $\delta^{13}C$ and $\delta^{15}N$ values. Unfortunately, no $\delta^{34}S$ baseline exists for the region or time period and so some universal trends and expected values from other research will have to be utilized. A zooarchaeological study by Fuller et al. (2020) expanded on the Sidonian fish remains analyzed by Schutkowski and Ogden (2011) to also include roughly contemporaneous Bronze and Iron Age fish from the Syrian site of Tell Tweini. This study confirmed that marine fish along the Levantine coast show higher $\delta^{13}C$ values than terrestrial sources, and that fish from freshwater and brackish environments overlap in $\delta^{15}N$ and $\delta^{13}C$ values with terrestrial ranges (Fuller et al., 2020).

There are interpretations of carbon and nitrogen stable isotope ratios beyond traditional dietary studies. The same stepwise enrichment in nitrogen that allows the observation of predator–prey relationships also enables researchers to examine breastfeeding practices, as an infant breastfeeding will be feeding one trophic level higher than their mother (Fuller et al., 2006). Stable isotope values can be examined to interpret foods used during weaning to supplement breast milk (i.e., complementary foods), or to compare childhood foods with those consumed by adults by comparing tooth and bone collagen samples of adults (Tsutaya, 2017; Tsutaya & Yoneda, 2015). Bayesian analysis of bulk bone collagen in infants and children to estimate weaning and childhood feeding practices have already been conducted using isotopic data from Sidon (Stantis, Schutkowski, & Sołtysiak, 2020). Further investigation of breastfeeding and weaning in Sidon is outside the bounds of this study, and so these potential variations in values from breastfeeding are variables to account for rather than a research focus.

As bone continues to remodel throughout life (Hedges et al., 2007), carbon and nitrogen stable isotopes from bulk collagen

will represent the averaged diet from the last few years of life, with adult bone representing roughly the last 10 years of life while non-adult bone experiences much faster turnover (Geyh, 2001; Hedges et al., 2007). Bone collagen turnover is greatly increased in subadults relative to adults: the bones of infants and young children undergo complete turnover in less than a year (Szulc et al., 2000). Tooth enamel, however, never remodels (Hillson, 1996). As such, analysis of enamel will record a snapshot of time when the tooth is forming, with no remodeling or turnover.

Beyond diet, extreme undernutrition or taxing the body due to illness or growth may also play a role in changes in stable isotope ratios over time. Studies of modern anorexic patients have shown that changes in nitrogen and carbon isotope ratios, previously interpreted as primarily related to dietary factors, may equally be the result of physiological stress, with nitrogen rising and carbon falling during the extreme chronic undernutrition experienced during anorexia, and nitrogen falling and carbon rising as body mass index increases if treatment and aftercare are administered (Baković et al., 2017; Mekota et al., 2006; Neuberger et al., 2013). If $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ display negative covariance (i.e., if $\delta^{15}N_{collagen}$ values rise over time while $\delta^{13}C_{collagen}$ values fall), then extreme physiological stress needs to be considered. Both bone and dentin collagen are subject to non-dietary factors affecting isotope values, but incremental sections do allow an approach to identifying these factors that is much more immune to environment-related shifts and more tightly controlled by genetics than bone (Beaumont et al., 2018; Cardoso, 2007; King et al., 2018).

3 | METHODS

Most of the Sidon assemblage is curated at Bournemouth University (UK). As an active excavation, some recently excavated inhumations were stored at the Sidon College Site in Saida/Sidon, Lebanon. Permissions to export samples from these burials for destructive analysis at the laboratories in the UK were granted by the Directorate General of Antiquities in Lebanon.

Age and sex estimations were determined using standard bioarchaeological methods (Brickley & McKinley, 2004; Buikstra & Ubelaker, 1994). To compare burial types, burials are typified as "pit," "constructed tomb," or "jar." Burial 44B, an adult found in the fill of the jar burial 44A, is unclassified and excluded from this comparison.

For dietary isotopes from bone collagen, samples of ~800 mg were taken from cortical bone, excluding bones with pathological changes on the principle that changes in the metabolic pathways of the tissue as a result of disease may affect the isotope values (Katzenberg & Lovell, 1999). For isotopic analysis of dental enamel, second permanent molars or permanent premolars (first or second) were selected as these teeth, whether mandibular or maxillary, complete crown formation between 5 and 8 years of age of the individual (AlQahtani et al., 2010).

Teeth with cavitated carious lesions were avoided to minimize variation from pathological changes to the enamel (Plomp et al., 2020). In the instance of plural tombs that were so commingled individuals could not be confidently separated and identified, a single isolated and sided element (e.g., left humerus, left upper second molar) was chosen to minimize the chances of sampling the same individual twice.

Fifty-six enamel samples were collected for $^{87}Sr/^{86}Sr$, $\delta^{13}C_{carb}$, and $\delta^{18}O$ analysis. Three Bronze Age terrestrial snail shells from the site were integrated as representing the local $^{87}Sr/^{86}Sr$ biosphere. Although domesticates (e.g., ovicaprines, cattle) have been excavated from the Middle Bronze Age layers in Sidon, the cultic activity surrounding the deposits led the site zooarchaeologists to posit that these animals might have been brought in for special ritual occasions (Chahoud & Vila, 2012; Doumet-Serhal & Shahud, 2013). Further, these animals from ritual contexts likely do not represent the population's regular diet. As such, these animals were not selected to represent the local biosphere. The carbon and nitrogen stable isotope data from Schutkowski and Ogden (2011) and Kharobi et al. (2021) are integrated ($n = 93$) with additional sulfur stable isotope results. All samples meeting the weight criteria of ≥1 mg were also analyzed for $\delta^{34}S$.

3.1 | Analysis of $\delta^{13}C_{coll}$, $\delta^{15}N$, and $\delta^{34}S$ from bone collagen

Stable isotopes analyses of some individuals has already been conducted and published elsewhere (Schutkowski & Ogden, 2011; Stantis, Schutkowski, & Sołtysiak, 2020), but this research expands dietary stable isotope analysis of the Sidonian assemblage with more individuals analyzed as well as the inclusion of sulfur isotopes. The first dietary stable isotope analysis was carried out at the School of Applied Sciences in Bradford University and the new data were produced at the National Oceanography Centre Southampton (NOCS), both in the United Kingdom. At Bradford, samples were measured using a Thermo Flash EA 1112 and introduction of separated N_2 and CO_2 to a Delta plus XL via a Conflo III interface.

At NOCS, carbon, nitrogen, and sulfur stable isotope values were measured simultaneously using an Elementar PYRO Cube Elemental Analyzer running in CNS mode and equipped with a thermal conductivity detector interfaced with an Isoprime VisION continuous flow isotope ratio mass spectrometer. Acetanilide (Merck, Darmstadt, Germany) and sulfanilamide (Elementar UK, Stockport) were elemental standards for weight percentage carbon, nitrogen, and sulfur, with USGS40 and USGS41 as international reference materials (USGS, Reston, VA). The Protein Standard (B2155, Elemental Microanalysis Ltd.) was interspersed for quality control over runs and yielded an analytical reproducibility better than 0.14‰ (2 *SD*) for $\delta^{13}C$ and 0.18‰ (2 *SD*) for $\delta^{15}N$ on all runs.

Although there may be inter-laboratory variation in stable isotope values, collagen stable isotope results tend to be relatively comparable between different laboratories, especially if the preparation methods are identical between labs (Pestle et al., 2014). Twelve duplicate samples run at Bradford and NOC were analyzed to test inter-laboratory variability.

Collagen quality indicators are used to ensure data integrity for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ from collagen. Modern bone samples have %C values between 15% and 47% by weight, and %N values fall between 5% and 17% (Ambrose, 1990; Ambrose & Norr, 1992). Poorly preserved and/or contaminated archaeological samples will have %C and %N values outside of these ranges. Further, samples had to display C/N ratios within 2.9 and 3.6 to be included and analyzed further. For sulfur, C/S ratios of 600 ± 300, N/S ratios of 200 ± 100, and a %S by weight of 0.15%–0.35% are criteria for acceptable sulfur results of mammal bone (Nehlich & Richards, 2009).

3.2 | Analysis of $\delta^{13}C_{carb}$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ from tooth enamel

Initial sample preparation was conducted in the Department of Archaeology and Anthropology's Dorset House laboratory at Bournemouth University (UK). After burring to remove the outer surface, enamel was removed from the tooth using a dental cutting instrument with a rotary saw attachment. Any dentine attached was gently burred. The enamel was powdered in an agate mortar and pestle and then pretreated with 0.1 M acetic acid at room temperature for no longer than 4 h. The powders were then rinsed 3x with ultrapure water and then dried in a 50° oven overnight.

Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope ratios were measured in the Department of Earth Sciences at Durham University (UK) in the carbonate (CO_3) component of tooth enamel following the procedures of Bentley et al. (2007). For each tooth, ~2 mg of powdered sample was reacted with 99% ortho-phosphoric acid for 2 h at 70°C. The resultant gas mix of helium and CO_2 was then purified in a Thermo Fisher Scientific Gasbench II then passed directly into a Thermo Fisher Scientific MAT 253 gas source mass spectrometer for isotopic analysis. Duplicate analysis of samples yielded a precision with a mean difference of 0.24‰ for $\delta^{13}C$ and 0.22‰ for $\delta^{18}O$. International reference carbonate materials NBS 19 ($n = 3$), IAEA-CO-1 ($n = 3$), LSVEC ($n = 3$) were analyzed during each run to monitor performance and normalize the isotopic data. Two internal standards: carbonate DCS01 ($n = 7$) and equid tooth enamel Dobbins ($n = 2$) were also analyzed in each run. International standards yielded reproducibility better than 0.12‰ (2 *SD*) for $\delta^{13}C$ and 0.20‰ (2 *SD*) for $\delta^{18}O$. All values have been normalized to the accepted values of +2.49‰ VPDB and − 46.6‰ VPDB for $\delta^{13}C$, and − 2.40‰ VPDB and − 26.70‰ VPDB for $\delta^{18}O$, for IAEA-CO-1 and LSVEC respectively. In order to compare $\delta^{18}O_{carb}$ values to local water, the carbonate values were converted to drinking water ($\delta^{18}O_{dw}$) using Daux et al.'s equation 6 (Daux et al., 2008).

Strontium isotope ratios were measured using a ThermoFinnigan Multi-collector ICP Mass Spectrometer (MC-ICP-MS) in the Department of Earth Sciences at Durham University (UK). Reproducibility of the standard NBS987 during sample analysis was 0.7102505 ± 0.000016 (2 *SD*, $n = 32$). All NBS987 values have been normalized to the accepted value of 0.710240 (Johnson et al., 1990; Terakado et al., 1988).

Fourier transformation infrared spectroscopy (FTIR) analysis can be utilized for preservation assessment (Beasley et al., 2014; France et al., 2020; Hollund et al., 2013). Although $\delta^{18}O$ and $\delta^{13}C_{carbonate}$ can have preservation issues, especially surrounding recrystallization of the inorganic matrix, FTIR was not included in this study as spectroscopic indicators are not necessarily reliable for ascertaining the level of diagenetic changes (Trueman et al., 2008). Bone can be used in studies where diagenetic effects are not thought to have affected $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values, but tooth enamel is more resistant to leaching and contamination from the burial environment (Hoppe et al., 2003; Trickett et al., 2003).

Other than strontium the stable isotopes used in this study (carbon, nitrogen, oxygen, and sulfur) are expressed as a ratio of heavy versus light isotopes and is reported using the delta notation (δ): $\delta = [(R_{sample}/R_{standard} - 1) * 1000]$ where R is $^{13}C/^{12}C$, $^{15}N/^{14}N$, $\delta^{34}S$, or $^{18}O/^{16}O$ in this study (Hoefs, 2009; Sharp, 2017). All are presented relative to international standards: AIR for $\delta^{15}N$, VSMOW for $\delta^{18}O$, and VPDB for $\delta^{13}C$ and $\delta^{34}S$.

Statistical analysis and data visualization were conducted using R software (Core Team, 2000) and data management were followed using the IsoArcH structure for managing isotopic data (Salesse et al., 2018). The data supporting the findings of this study are available within the article and its supplementary materials.

4 | RESULTS

Summarized descriptive statistics for all isotopes are in Table 1. For bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, 92 met collagen quality criteria. Of the 22 samples which yielded the minimum weight for simultaneous $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ analysis, only seven met collagen quality criteria for sulfur. All human data, including collagen quality and element sampled are presented in Table S1. Snail shell $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ data are presented in Table 2.

TABLE 1 Descriptive statistics summaries of the isotopes analyzed in this paper

	Min	Max	Mean	*SD*	*n*
$\delta^{13}C_{carb}$	−13.8	−11.4	−12.8	0.5	56
$\delta^{18}O_{carb}$	24.6	32.8	26.8	1.1	56
$^{87}Sr/^{86}Sr$	0.706469	0.708858	0.708347	0.00043	56
$\delta^{13}C_{coll}$	−20.1	−17.9	−19.3	0.5	92
$\delta^{15}N$	5.2	12.2	8.8	1.4	92
$\delta^{34}S$	7.9	13.1	10.4	2.0	7
$\Delta^{13}C$	4.5	6.5	6.4	0.7	36

TABLE 2 Snail shell $^{87}Sr/^{86}Sr$ and carbonate results

Snail ID	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr$ SE	$\delta^{13}C_{carb}$	$\delta^{18}O_{carb}$
Sidon1	0.708057	0.000008	−7.58	29.7
Sidon2	0.707704	0.00001	−7.46	30.6
Sidon3	0.707729	0.000006	−7.17	29.3

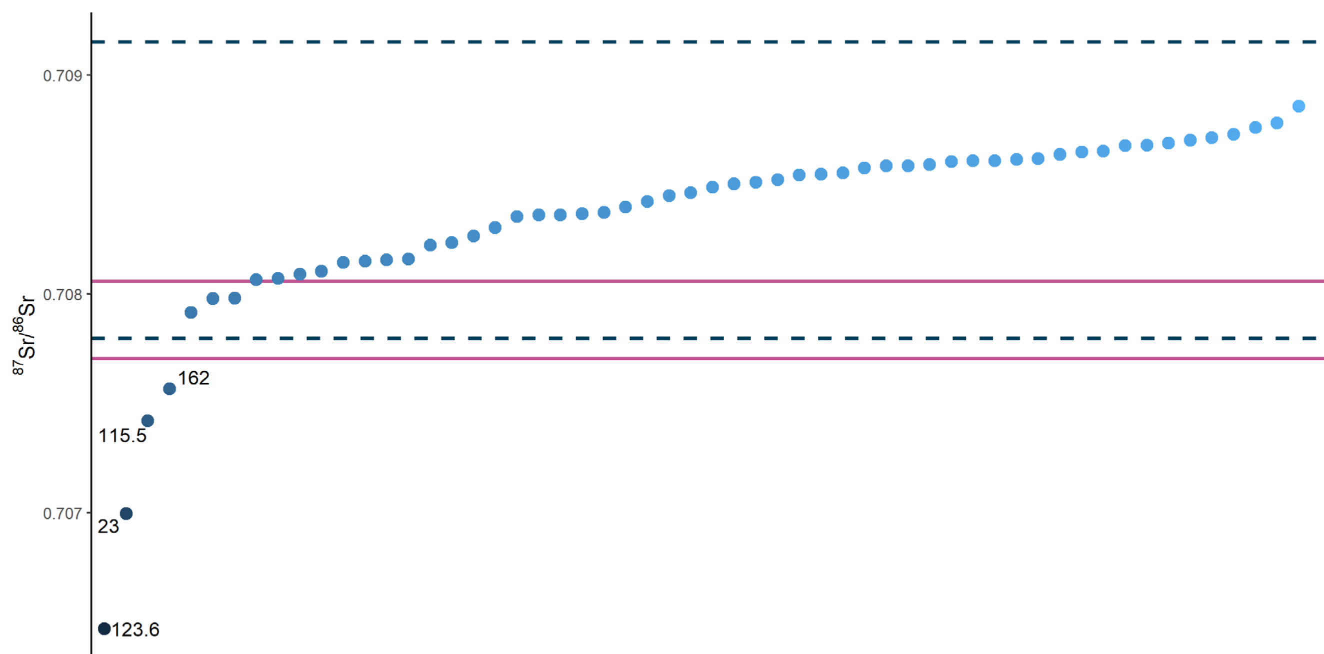


FIGURE 3 $^{87}Sr/^{86}Sr$ values. Snail shell biospheric $^{87}Sr/^{86}Sr$ range (solid line) and median ± 1.5 IQR from human data (dashed) delineated

Using Shapiro–Wilk normality tests, $^{87}Sr/^{86}Sr$, $\delta^{18}O$, and $\delta^{13}C_{coll}$ data are not normally distributed ($p \leq 0.05$). $\delta^{13}C_{carb}$, $\delta^{15}N$, and $\delta^{34}S$ are normally distributed data ($p > 0.05$).

4.1 | $^{87}Sr/^{86}Sr$ and $\delta^{18}O$

The snail shells do not seem to represent the range of humans moving in Sidon as evidenced by the snail's restricted $^{87}Sr/^{86}Sr$ values in relation to the human ranges (Figure 3). Considering this, the median value of the human enamel samples ±1.5 IQR is used to establish the "local" range, with individuals outside 1.5 IQR from the mean identified as non-locals in the assemblage using $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. This is similar to other studies which use the human mean ± 2*SD* in the absence of biospheric data (e.g., Shaw et al., 2010; Stantis et al., 2016), but in non-normally distributed data such as this study's $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ data, the use of median and IQR is more appropriate.

Four individuals are outliers in terms of $^{87}Sr/^{86}Sr$ ratios: Burial 23, Individual 1 from Tomb 123, Individual 5 from Tomb 115, and Burial 162. Two outliers are identified using $\delta^{18}O$, two individuals from commingled tombs: Individual 1 from Tomb 123 who had also displayed non-local $^{87}Sr/^{86}Sr$ values and another individual from Tomb 115, Individual 3 (Figure 4). $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analysis combined brings the total percentage of non-locals identified using isotopic analyses to 8.9% (5/56). Four of those five individuals were buried in constructed tombs while one (Burial 162) was a pit burial. Only two of these non-locals had sufficient skeletal preservation to estimate age and sex; Burial 162 is a Middle/Old Adult (45–55 years of age) Male, and Burial 23 is a Middle-Aged (40–50 years of age) possible male.

4.2 | Collagen carbon, nitrogen, and sulfur

The 12 duplicate samples (where both duplicates showed good collagen quality) showed little variability ($\delta^{13}C$ absolute mean difference = 0.14‰, $\delta^{15}N$ absolute mean difference = 0.03‰). There was not a significant difference between the two labs in either in $\delta^{13}C$ values ($t[9] = -1.021$, $p = 0.334$) or $\delta^{15}N$ values ($t[9] = -0.141$, $p = 0.891$). The outcome suggests that the results from the two labs can be combined with confidence and that inter-laboratory variability will not affect interpretation. For the duplicated samples, the NOCS samples will be used for statistical and visual analyses instead of those analyzed at Bradford.

The scatterplot of Sidonian human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values laid over the animal bone collagen values of ovicaprines, marine fish, and cattle collected by Schutkowski and Ogden (2011) show values aligning with terrestrial $\delta^{13}C$ values (Figure 5). Statistically comparing locals and non-locals is not appropriate given the small group size of non-locals with collagen isotope data ($n = 2$); qualitative examination shows that those identified as non-locals do not display outlying carbon or nitrogen stable isotope values (and no non-locals had enough collagen yield for sulfur analysis).

There were no significant differences between the sexes regarding $\delta^{13}C$ and $\delta^{15}N$ values using a one-way MANOVA ($F[1, 38] = 1.895$, $p = 0.165$). There were significant differences between burial types regarding $\delta^{13}C$ and $\delta^{15}N$ using a one-way MANOVA ($F[2, 88] = 7.284$, $p = 0.001$), but as many infants and young children are buried in jars, this difference between burial types is likely a reflection of the effects of breastfeeding. Removing those potentially breastfeeding (≤ 5 years of age) from the cohort for this test creates non-significant results between burial types ($F[2, 63] = 0.0225$, $p = 0.978$).

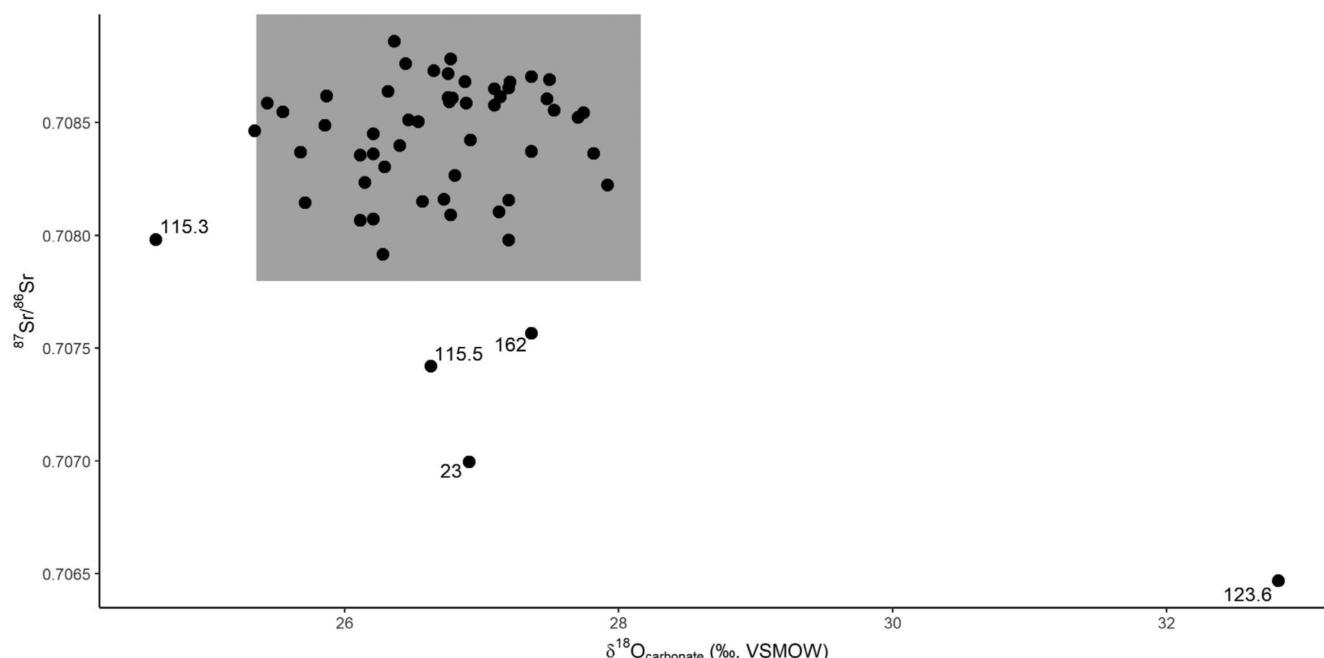


FIGURE 4 $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of all individuals. Shaded box represents median ± 1.5 IQR for isotopes, shading the "local" isotopic values for Sidon. Non-locals labeled

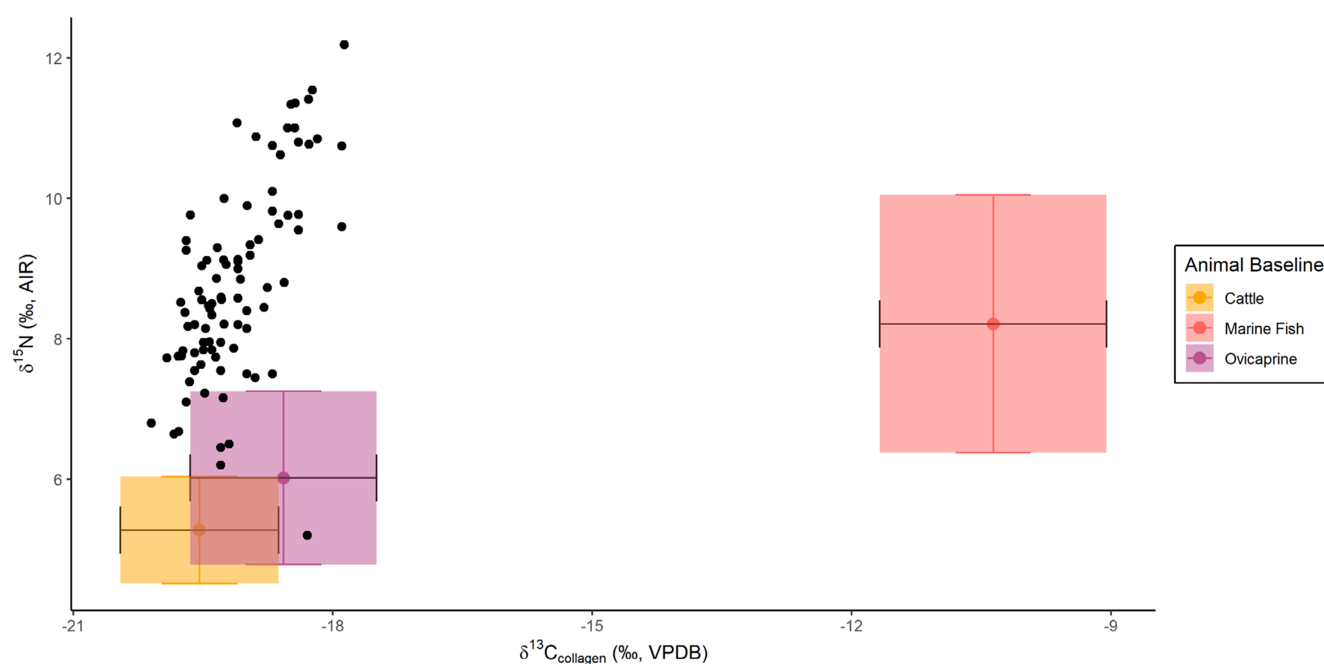


FIGURE 5 $\delta^{13}C$ and $\delta^{15}N$ values of all Sidonian humans, with faunal baseline data (cattle, marine fish, and ovicaprines) from Schutkowski and Ogden (2011)

4.3 | $\delta^{13}C_{carb}$

Potential differences between the sexes and burial typologies regarding $\delta^{13}C_{carb}$ values are tested separately from $\delta^{13}C$ and $\delta^{15}N$ to increase power. There are no significant differences in $\delta^{13}C_{carb}$ values between the sexes ($F[1, 35] = 1.102$, $p = 0.301$) nor between burial types ($F[2, 52] = 0.536$, $p = 0.588$), even with infants and young children included in the cohort.

$\Delta^{13}C$ values ($\delta^{13}C_{carbonate\text{-}collagen}$) could be calculated for 36 individuals with both bone collagen and enamel carbonate $\delta^{13}C$ values. These calculated values are in Table S1. These values range between 4.51 and 7.56, with a mean ± 1*SD* of 6.41 ± 0.66.

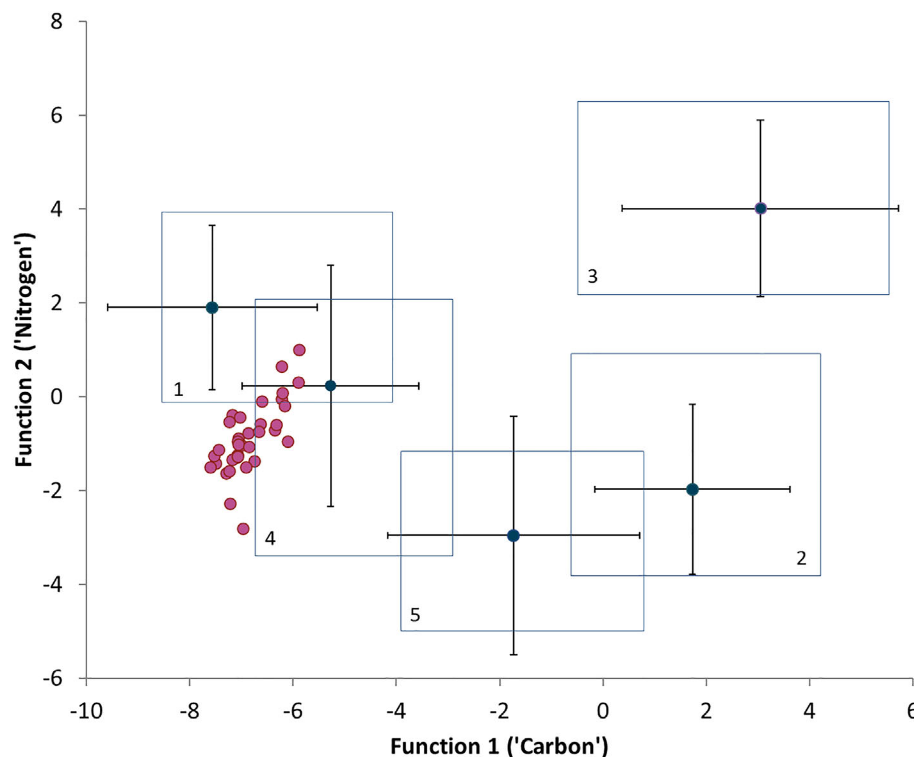


FIGURE 6 Discriminant function analysis of stable isotope data from Sidon plotted against diet clusters generated by Froehle et al. (2012). Clusters represent the following diets: (1) 100% C_3 diet/protein; (2) 30:70 C_3:C_4 diet, >50% C_4 protein; (3) 50:50 C_3:C_4 diet, marine protein; (4) 70:30 C_3:C_4 diet, ≥65% C_3 protein; (5) 30:70 C_3:C_4 diet, ≥65% C_3 protein

4.4 | Multivariate discrimination

Although the carbonate and collagen come from two different tissues representing two different time periods of the individual's life, combining the bulk bone collagen data with the $\delta^{13}C_{carbonate}$ in a multivariate model provides another means of examining whole diet.

Discriminant function analysis suggests a diet consisting of between 65% and 100% C_3 protein with some sourcing from C_4 terrestrial foods (Figure 6). All samples fall within or near both Clusters 1 and 4. Cluster 1 represents a 100% C_3 diet and Cluster four represents a 70:30 C_3: C_4 diet with ≥65% protein.

5 | DISCUSSION

5.1 | Movement

The attempt to use local snail shells as a biospheric proxy of local humans was unsatisfactory. Evans et al. (2010) warn against snail shells, as they can be more reflective of rainwater when used for strontium and oxygen than the local soil environment. The Sidonian snails might have been good reflections of the restricted local area of the city, but as the inhabitants of Sidon were known to rely on the hinterlands for food sources, a broader $^{87}Sr/^{86}Sr$ range is reflected in the human assemblage. This discrepancy between local environment and human $^{87}Sr/^{86}Sr$ values due to behavior and bioavailable contribution of human diet is a known "cautionary tale" that has been observed in other paleomobility studies (Gregoricka et al., 2020; Kendall et al., 2013). A biospheric map of Lebanon would ameliorate this problem.

Biospheric data from Northern Israel and the Golan Heights by Hartman and Richards (2014) provides some comparative data on similar geological formations in the Levant. In Northern Israel, calcareous sandstone and coastal deposits similar to the Sidon coast displayed a restricted range of $^{87}Sr/^{86}Sr$ ratios, between 0.7088 and 0.7092. Plants and invertebrates on Cretaceous sedimentary soils (similar to those found east of Sidon) display $^{87}Sr/^{86}Sr$ ratios between 0.7079 and 0.70883. This range fits within Sidon humans' mean ± *SD* in this study, 0.708347 ± 0.00043 and supports the hinterlands reliance hypothesis.

As a coastal city with major trade networks including along the Levantine coast, Egypt, Cyprus, Crete, and inland to the south and east (Bader et al., 2009; Charaf, 2014; Doumet-Serhal, 2004; Doumet-Serhal, 2008; Veron et al., 2011), it is perhaps surprising that so few buried are non-locals. Non-locals largely either did not settle in Sidon or were buried at a different location in the ancient city. There is also the issue of equifinality (Torrence, 1986; Torrence et al., 1992), where people from other parts of the world might have $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values overlapping with Sidon, but they are indistinguishable from locals using these methods. This is a common problem with paleomobility isotopic studies, especially in regions where the biospheric baseline is not well-established or biospheric values of wide geographic areas are known to overlap (Stantis et al., 2015; Stantis et al., 2019; Stantis, Kharobi, et al., 2020; Wang & Tang, 2020).

In addition, isotopic analysis in this research only captured evidence of childhood residence. Combined with excavations, we only know two points of movement in these individuals' lives: where they were raised, and where they were buried. The Sidonians analyzed in this study might have stayed local their whole lives, navigating life in

an interconnected port city, or they might have traveled across this ancient Mediterranean world during their lifetime before returning to their homeland. Given the apparent importance of Sidon as a center of exchange, Sidonians might have traveled lengthy periods of time for trade before returning to the settlement in which they grew up. Alternatively, those in this assemblage with local values might have lived the entirety of their lives in Sidon, ensuring the movement of goods in their increasingly interconnected world without themselves moving. The lack of heterogeneity in strontium ratios could be either of these scenarios.

Those individuals identified as non-locals are all from constructed tombs, except for Burial 162 which was heavily disturbed in antiquity. Tombs 115 and 123 are richly appointed constructed tombs with multiple burials, where individuals with non-local signatures (Individuals 3 and 5 from Tomb 115, Individual 1 from Tomb 123) were interred with burial practices similar to the others in their collective tombs. In both tombs there are evidence of economic wealth in the forms of jars, copper and/or bronze objects, scarabs, cylinder seals, and glass beads. Tomb 115, with an estimated MNI of 8 and five individuals analyzed in this study, represents commingled human remains showing some signs of organizing by skeletal element (e.g., skulls were all placed in the north end). Under the commingled remains of Tomb 115, heavily disturbed remains of a primary burial (Burial 121) were found, likely related to the commingled material. The primary burial has local isotopic values, but is associated with a cylinder seal bearing Anatolian and Mesopotamian styles/subjects (Doumet-Serhal, 2018–2019). Like Burial 115/121, Burial 123 consists of both articulated and disarticulated remains (MNI = 7). These disarticulated remains were deposited in the northeast and northwest corners of the tomb.

Multiple burials are common within the site but in communal tombs, skeletons were all placed more, or less together and not neatly positioned, precluding separation of the commingled remains or attribution of burial goods to any particular individual within these plural graves. It is worth noting that other burials with exotic burial goods such as Burial 121 and Burial 100 (Doumet-Serhal, 2011) have isotopic values suggestive of being raised in Sidon (or areas with similar geological and climatic environments), possibly showcasing the exotic goods being moved through this cultural hub by local elites. These tombs holding non-local individuals do not appear to be differently constructed or organized from those containing only locals.

A bronze fenestrated axe beside the left shoulder of Burial 23 (Doumet-Serhal, 2003b) makes it a weapons-associated burial, or 'warrior burial'. These burials associated with bronze weaponry are thought to be elite males in the Bronze Age Near East, with the weaponry of a valued and rare metal attributed to social status and cultural values awarded to the warrior elite (Cohen, 2012). The other weapons-associated burials at Sidon show local isotopic values (Kharobi et al., 2021). Along with the bronze axe, Burial 23 was also notably buried with an imported jar from Upper Egypt, possibly the Theban area (Forstner-Muller & Kopetzky, 2006).

Although the subgroup of non-locals is small at Sidon and so interpretive value of defining this group should be viewed cautiously, those who had sufficient preservation to estimate sex were identified as male. Ancient Near East marriage practices have been postulated to be patrilocal (Al-Shorman & Khwaileh, 2011) and so some non-local women might have been expected. Instead, Sidonian marriages might have occurred between families within the region, and inter-regional connections were forged in other ways. Analysis of dental non-metric traits between the warrior burials did not highlight Burial 23 as genetically distinct from the group (Kharobi et al., 2021), although this fits with genomic analysis of the wider region which found that the people of the ancient Near East shared common genetic connections (Haber et al., 2017). Haber et al.'s comparison of the Sidonian genomic information with other contemporaneous genomic data around the Near East suggests that, while there was abundant assortment of cultural identities during the time period, the people seem to have shared common genetic ties. As such, studies of broad population histories and ancestry within the Levant might not show movement in the same way isotopic investigation of individual movement would. It is worth noting that recent genomic studies in the northern Levant (Alalakh and Ebla in modern Turkey and Syria, respectively) have found extensive admixture with populations from the Caucasus and Anatolia from the Bronze Age (Ingman et al., 2021; Skourtanioti et al., 2020); this part of the Levant may have even been a stopover to more southerly regions for these northern peoples (Agranat-Tamir et al., 2020). More extensive genetic analysis of Sidon might find similar movement and admixture on a wider scale. Sex determination using genetic or peptide analysis (Stewart et al., 2017) would help with making stronger interpretations about sex-based movement in the Sidonian human assemblage, where there is a wide range of preservation.

Regarding comparative isotopic studies of mobility, the only other MBA assemblage within the same cultural sphere as Sidon is the city of Avaris (the site of Tell el-Dab'a) in the northeastern Nile Delta (Bietak, 2010; Bietak, 2013). Strontium analysis of the assemblage at this site revealed that most (40/75 or 53%) originated from outside the Nile Delta (Stantis, Kharobi, et al., 2020). Comparative isotopic data from this region and time period are scarce, but these two coastal hubs are in stark contrast in terms of relative individual movement.

5.2 | Diet

Further bulk bone collagen sampling and analysis agrees with the general findings of Schutkowski and Ogden (2011): Sidonians in the Middle Bronze Age were relying on terrestrial C_3 plants and domesticates who also relied on a C_3-based diet. With no contemporaneous baseline, interpretation of the sulfur isotope results is difficult. The closest comparison to Sidon is in Egypt (Touzeau et al., 2014), where the values from the Sidonians here are similar to values observed in Nile perch and later period Egyptians (ca. 526 BCE–400 CE). This might suggest some reliance not on the marine fish observed in the funerary offerings but instead freshwater fish, which can have a wide range of $\delta^{34}S$ values intermediate to and overlapping with terrestrial

and marine δ^{34}S ranges. The freshwater fish from Sidon displayed among the highest δ^{13}C values, roughly 10 per mill higher than the human mean average, but this is only a single data point and different freshwater environments are known to have wide-ranging δ^{13}C and δ^{34}S values dues to the heterogeneous sources of carbon and sulfur in these types of environments.

Deeper examination of social status and diet showed no difference by sex or burial type. Food choice and access as related to social status, if there were any differences in MBA Sidon, are not observable using isotopic analysis. This might be because many of the high-status foods, were also C_3 plants and indistinguishable from other, less desirable C_3 plants (e.g., if emmer bread were preferred over barley). There is also the case when foods are made of the same ingredients, but more intensive preparation makes one form more desirable (e.g., finer ground wheat to make a softer dough).

All Δ^{13}C values were above 4.5, further supporting a terrestrial diet with little/no marine input. Multivariate discriminate function analysis of three stable isotopes values ($\delta^{13}C_{collagen}$, δ^{15}N, and $\delta^{13}C_{carb}$) are also in agreement, with some potential C_4 input noted.

5.3 | Where's the fish?

Although the fish bones recovered from funerary offerings were edible species and placed in relatively large quantities to resemble feasting (Doumet-Serhal, 2009), there is no isotopic evidence suggesting regular consumption of marine foods. Fish from freshwater and brackish environments might have been consumed, but these values can overlap with terrestrial foods in the Levantine environment (Fuller et al., 2020). The only freshwater fish identified and isotopically analyzed at Sidon was Nile perch (*Lates niloticus*), estimated to have been exported to the Levantine coast from the Egyptian Nile Delta (Chahoud, 2016; Linseele et al., 2013).

The fish remains found in Sidon might be offerings to provision the dead—the act of appeasing the dead with food and libation to both give honor to ancestors and avoid the spirits' wrath are observed across Mesopotamia and the Levant (Bayliss, 1973; Lewis, 2014). If these fish are attributed with the afterlife, are they only appropriate as funerary offerings during ancestor veneration? Some of the fish placed at Sidon are whole skeletons (van Neer, 2006) and might not have been consumed in any part by the living. Royal cults lavishing honors and appeasements to the death occurred as often as once every lunar month (Van der Toorn, 2014) though some remembrance feasts were annual in the wider region (Bayliss, 1973). If fish were specifically tied to the afterworld, the living, if they were consuming the feasting food alongside their ancestors, might have consumed fish rarely. Further dietary isotopic analysis of Bronze Age Levantine people will address whether there is a pattern of avoidance in this food, or if Sidon alone made use of the Mediterranean Sea as a passageway for trade and contact but not as a larder.

This discrepancy might also be a result of changes in subsistence strategies and preferred foods over time. While those buried in Sidon might not have consumed large proportions of marine foods, those who offered funerary foods to the Middle Bronze Age burials might have consumed marine fish themselves, sharing their meals with the revered dead. Without later MBA burials found, we cannot test the dietary values of those who might have given the offerings.

6 | CONCLUSION

The relatively large MBA assemblage of Sidon provides one of the largest isotopic data sets to date in the ancient Levant, providing an opportunity to both characterize general population diet as well as investigate subgroup and individual diet and movement. The elite tombs as identified through funerary archaeology at this Mediterranean trade center appear to have more immigrants than those of lower social status, but migration into Sidon appears to have been limited regardless of social status. Diet was generally terrestrial C_3-based foods with no appreciable marine input, despite the apparent ritual importance of fish in funerary offerings venerating the dead. Differences in diet between social groups, if present, were not observable using stable isotopes analysis.

Future research would benefit from a local biospheric baseline including animals of the hinterlands to better represent the human range of movement. Bulk bone collagen of infant and young children from Sidon were utilized as evidence of weaning and childhood feeding practices in a previous Bayesian analysis (Stantis, Schutkowski, & Sołtysiak, 2020), but the generally good collagen preservation of Sidon could allow expansion of investigation of age and agency in the future with incremental sampling of dentine collagen (Beaumont et al., 2015; Czermak et al., 2020) to create dietary profiles with high temporal resolution.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS

Chris Stantis: Conceptualization (equal); data curation (lead); formal analysis (lead); investigation (equal); project administration (equal); validation (lead); software (lead); writing - first draft (lead); writing - review and editing (lead). **Arwa Kharobi:** Conceptualization (supporting); data curation (supporting); formal analysis (supporting); investigation (supporting); project administration (supporting); validation (supporting); writing – review and editing (supporting). **Nina Maaranen:** Conceptualization (supporting); formal analysis (supporting); investigation (supporting); methodology (supporting); project administration (supporting); writing – review and editing (supporting). **Geoff M. Nowell:** Formal analysis (supporting);

methodology (supporting); resources (equal); software (equal). **Colin Macpherson:** Methodology (supporting); resources (supporting); software (supporting); writing – review and editing (supporting). **Claude Doumet-Serhal:** Conceptualization (supporting); funding acquisition (supporting); project administration (supporting); resources (equal); writing – review and editing (equal). **Holger Schutkowski:** Conceptualization (equal); funding acquisition (lead); investigation (equal); project administration (equal); resources (equal); supervision (lead).

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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